

## Project Report

### Introduction

Iron Mountain is the host of massive sulfide deposits that were mined for copper, zinc, gold, silver, and pyrite (for sulfuric acid) between the early 1860s and the early 1960s. The mines at Iron Mountain represent the largest within the West Shasta mining district of northern California.<sup>1</sup> The sulfide deposits at Iron Mountain occur as tabular masses with >95% sulfide. The deposits are pyrite-rich, with copper and zinc occurring primarily as chalcopyrite and sphalerite, respectively. The host rocks in the Iron Mountain area include the Balaklala rhyolite, a felsic volcanic rock that has been hydrothermally altered to contain the minerals illite (sericite), chlorite, and albite as well as residual quartz, and the Copley Greenstone, a meta-andesite.

The Richmond Mine at Iron Mountain was actively mined for copper and zinc by underground methods between the 1920s and 1950s. The Richmond Mine is notorious for having extremely acidic mine drainage: the water leaving the Richmond Adit has a pH around 0.5 and extremely elevated concentrations of sulfate, iron, and other metals.<sup>2</sup> Early reconnaissance samplings resulted in characterization of the extremely acidic mine waters (pH values from -3.6 to +0.5) and a variety of iron-sulfate efflorescent salts.<sup>3</sup>

In this project have paid special attention to the study of iron oxy/hydroxysulfates in natural selected samples from Iron Mountain, California since they have been recently identified by on-surface (MER) and orbital (OMEGA) instruments,<sup>4-8</sup> and due to the important role they play in defining potentially habitable past environments on Mars. Because of the importance of sulfates for the understanding of Martian evolution and surface processes, an unambiguous identification and characterization of those sulfates (and associated cations, hydration states ...) in the Iron Mountain site was pursued. We report the Raman spectroscopy of natural sulfate efflorescences from the Richmond Mine at Iron Mountain, California. Different mineral phases are identified within the samples.

### Field trip and sampling

As part of the Richmond Mine Superfund remediation program, the U.S. Environmental Protection Agency renovated a portion of the underground workings of the Richmond Mine during 1988-1990, which allowed access for sampling of water and efflorescent sulfate minerals.

Several levels of permissions are required when a field trip to the site is planned. For that purpose, Dr. Janice Bishop (advisor for this project) worked in collaboration with Dr. Jill Banfield (University of Berkeley) in order to get the permission through the

site manager, Mr. Rudy Carver. Unfortunately, access could not be granted by the time the proposed field trip was scheduled, thus preventing it from being carried out.

Under those circumstances, a new strategy was envisaged in order to pursue the main aim of the project: "to test Raman spectroscopy as a fast and accurate method for the characterization of potential terrestrial analogues of Mars and to explore the possibilities of the Raman technique onboard future missions to the Red Planet". Collaboration with Dr. Charles N. Alpers (USGS, Sacramento) and Dr. Max Coleman (JPL, Pasadena) was immediately established in order to get access to a set of subsamples collected by them and their teams in former field trips to the Iron Mountain site. They provided with samples from selected strategic sites within the Richmond Mine. To a certain extent, we feel fortunate to have had the chance to work together with Dr. Alpers and Dr. Coleman since they provided with a wide spectra of specific aqueous and solid samples that we would never have been able to collect at the site in the absence of an expert.

Mineral and water samples analyzed in this study were collected from the Richmond mine at Iron Mountain during 1990-92. Specific sites of sample collection were in the B and C drifts on the 2600 level, in the B'stope on the 2650 level, and in the E mainway, which connects the 2600 and 2650 levels along the C drift (Figure 1). Ambient temperatures in the mine workings were 35 to 47 °C. Mineral samples were preserved in acid-washed glass jars with Teflon-lined lids. Water samples were collected in flint glass containers with Teflon-lined lids. Parafilm was used to provide additional sealing of the lids. The samples were stored in a warehouse in Sacramento, California where temperature fluctuated between about 15 and 35 °C.

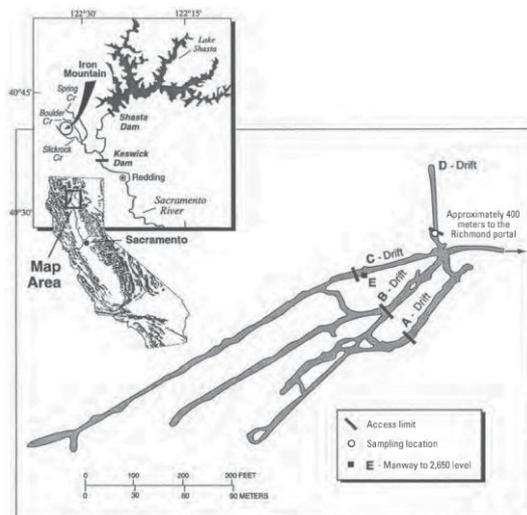


Figure 1. Location and plan map of the underground workings, 2,600 level, Richmond mine, Iron Mountain, California. Illustration from <sup>9</sup>



Figure 2. Picture of a slope in a sulfate-rich area near the California-Nevada border. P.S. (GPS coordinates N38.42940°, W119.06152°)

Additional samples were collected by P.S. from an old mining area, close to Bodie, California. These are mainly sulfate-bearing minerals with yellow-to-red-to-brown colors. The Raman analysis of the samples is under way.

## Results

Figure 3 shows the Raman spectra of several samples from Iron Mountain. Raman spectra were collected with a Renishaw inVia Raman microscope at SETI. Gypsum, ferricopiapite, copiapite, melanterite, coquimbite and voltaite are found in the samples. However the Raman spectra of the samples are difficult to analyze, showing overlapping bands and shoulders that may be due to the inclusion of unidentified sulfates and hydroxides in the main mineral matrix.

Ex-situ Raman microscopy has been used as a means of characterizing the mineralogy of Iron Mountain area. Gypsum and ferrous and ferric sulfates have been readily identified from their spectral fingerprints. A manuscript dealing with these results is in preparation and will be submitted to a specialized journal soon.

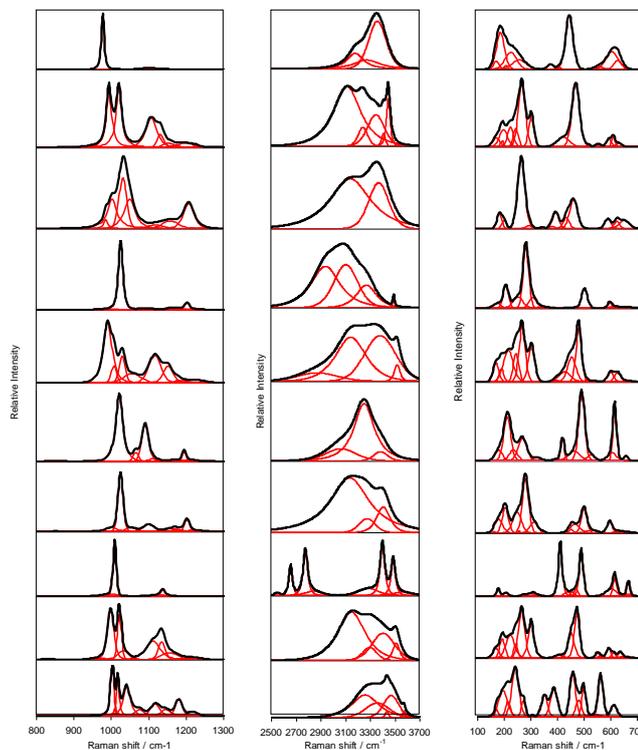


Figure 3. Raman spectra of samples from Iron Mountain

## References

- [1] Kinkelar et al. *U.S. Geol. Surv., Prof. Pap.* 285. **1956**
- [2] Alpers CN et al. *Mineral. Assoc. Can., Short Course Vol.* **2003**, 31, 407
- [3] Nordstrom DK and Alpers CN. *Proc. Natl. Acad. Sci. USA.* **1999**, 96, 3455
- [4] Gendrin A et al. *Science.* **2005**, 307, 158
- [5] Klingelhöfer G et al. *Science.* **2004**, 306, 1740
- [6] Clark BC, et al. *Earth Planet. Sci. Lett.* **2005**, 240, 73
- [7] Rieder R et al. *Science.* **2004**, 306, 1746
- [8] Lane MD et al. *Geophys. Res. Lett.* **2004**, 31, L19702, doi:10.1029/2004GL021231
- [9] Jamieson HE et al. *Can. Miner.* **2005** 43, 1225

Signed: Pablo Sobron